FABCHIPS: A WEAVING-BASED FABRIC PLATFORM FOR AFFORDABLE MICROFLUIDIC CHIP MANUFACTURE
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ABSTRACT
We are developing weaving as a platform to manufacture microfluidic chips for different biological assays. Our work advances published results [1] that showed proof-of-concept of the platform by demonstrating immunoassays performed with spiked human urine samples that show that fabric strips can be used to replace current lateral flow assays. In addition, we also report for the first time, concepts for multiplexing tests on fabric and also how electrochemical sensors can be manufactured by weaving electrodes into fabric. We believe such sensors represent a new class of microfluidic devices which could be integrated into clothing.

KEYWORDS: Fabric, Weaving, Sensors

INTRODUCTION
Several new platforms have been proposed to overcome challenges faced in the micro manufacturing of plastic and silicon devices. Chief among these has been the paper based diagnostics [2] where paper patterned into hydrophilic and hydrophobic regions can be used to direct fluid flow along complex paths. More recently, thread[3] and fabric have also been explored as possible mediums for performing simple capillary flow based diagnostic tests. Our group has previously shown that yarn coated with capture and detection reagents can be localized into specific regions using a handloom to construct lateral-flow like assays in fabric[1]. Even a simple hand-loom can be used to generate 1000s of strips everyday while industrial-scale power looms can manufacture large quantities for commercial purposes. To be commercially and clinically relevant, tests manufactured using any of these platforms need to be manufactured by a scalable process and also perform well with live clinical samples.

THEORY
Fabric-based sensors are manufactured in a 2-step process (Fig. 1). Yarn with the appropriate physical properties such as the number of twists-per-inch (TPI), ply and material is first coated with the appropriate reagent solutions that may contain surfactant, blocking agents or antibodies/antigens before it is dried and then woven onto a loom. This simple process ensures that both sensor patterning and reagent loading happen at the same time, eliminating the need for time-consuming alignment and spotting/printing steps needed in other platforms.

Figure 1 Schematic showing the process of fabric chip manufacture from start to finish. Cocoons are immersed in a boiling water bath to soften the sericin and permit unwinding of silk filaments (1). Multiple silk cocoon filaments are reeled to form a single strand of yarn (2). The single strand can then be twisted in different orientations before being combined with other strands to multi-'ply' the yarn (3) and (4). The yarn may then be subjected to a variety of treatments or combinations of treatments including boiling, coating with reagents or blocking (5). The coated yarn is dried before being woven. The yarn could be placed in the warp or weft way (see axes in bottom right). Multiple chips are simultaneously woven before being cut to form individual test strips (6).
EXPERIMENTAL

Immunosensors: To make the fabric based lateral flow immunoassay strips, reagents (detection antibody, capture antibody and control antibody) are coated on the weft yarn and woven in sequence at optimized distances from each other. Detection antibody and capture antibody Against β-hCG were purchased from Meridian Life Science Inc(USA), and control antibody was purchased from Merck India. 1μl/cm volume of detection antibody of 10 OD was coated on the 3 ply, 10 TPI silk yarn. Capture and control antibody concentrations were 1.9μg/cm and 0.6 μg/cm respectively on 4ply 25 TPI silk yarn. All reagents were coated on yarn using custom-made yarn coating equipment. Coated reagents were woven in the fabric and cut into 4mm*6cm strips and tested with known concentrations of β-hCG hormone spiked in male urine.

Multiplexed Sensor: Prototype of multiplexed fabric strips as shown in the fig.3, were woven by combination of the degummed and non degummed thread of 4 ply 25 TPI yarn. To make the multiplexed strips, non degummed (hydrophobic) warp yarns were interspersed with 4 to 10 degummed warp (hydrophilic warp) yarns. Sample pad was woven with degummed (hydrophilic) warp which allow the sample to spread only at sample pad reason to split the flow along the hydrophilic warp channel. Other than sample pad wefts were hydrophobic which prevented the intermixing of liquid sample from each other.

Electrochemical sensor: Fabric based electrochemical sensors for glucose detection were made by weaving three different conductive ink coated cotton yarn in weft direction. Degummed (hydrophilic) silk was used as warp and for the region between the electrodes. Carbon ink and Ag/Agcl ink were purchased from the Creative Material Ink (USA). Glucose Oxidase enzyme and the mediator (potassium ferricyanide) were purchased from the Sigma. Working electrode (WE) was made by coating carbon ink followed by coating Glucose Oxidase enzyme mixed with mediator (potassium ferricyanide). Counter electrode (CE) was made by coating carbon ink and reference electrode was made by using Ag/Agcl ink. These electrodes were woven in to the fabric and cut into the individual strips as shown in Fig. 4a and 4b. Different concentration of glucose was prepared by spiking the glucose in blood. Amperometric technique is used for the detection of glucose which measures the amount of current produced due to oxidation of glucose in presence of enzyme and redox mediator. The amount of current produced is proportional to the concentration of glucose.

RESULTS AND DISCUSSION

Immunassays
Several fabric-specific properties such as the number of twists per inch of the yarn, the ply of the yarn and the weaving style have been optimized to construct fabric based strips which have varying properties along the length of the strip (Fig. 2a). Results similar to currently available commercial lateral flow assays for the home pregnancy test have been obtained with spiked urine samples although the lower limit of detection must be further improved. We have found interestingly that the batch-to-batch variations in the intensity of the line in the fabric strips are less than commercially available strips (Fig. 1b). Further, multiplexed assays can be performed by using a combination of natural silk (hydrophobic because of the waxy sericin layer) and degummed silk (hydrophilic). A proof-of-concept device showing splitting of flows in fabric is shown in Fig. 3. Such devices are easy to fabricate in large numbers because of their simple designs.

TEST CONTROL

Figure 2a) Pictures of fabric strips run with spiked urine samples for β-hCG. The values of the hormone in mIU/mL are on the right. b)Pixel intensities of test line for different concentrations of the hormone. Low batch-to-batch variation was seen.
Figure 3a Fluid flowing from left to right is split into individual ‘lanes’. 2b. Small volume of fluid (5µl and 3 µl) flowing for longer length of 5cm and 3.5 cm respectively because of a combination of hydrophilic and hydrophobic yarns.

Figure 4  a) Patch of fabric with electrodes woven in. b) Strip of fabric as individual sensor. c) Confined flow of blood, d.) laminated strip, e) Peak current in amperometric detection vs. glucose concentration from glucose spiked in blood

Metabolite assays

Electrochemical assays for metabolites can be performed by coating yarns with conducting inks and then weaving them into fabric. Unlike screen-printing, only as much ink and enzyme as is needed for the tests is used leading to lower wastage and potentially lower costs. Our early results (Fig. 3) are obtained using amperometric sensing for glucose. Glucose samples spiked in buffers and glucose samples from whole blood were quantifiable using our fabric sensors and our own prototype detection system.

CONCLUSION

We have demonstrated the textile weaving is a scalable and viable platform for the manufacture of both immunoassays and clinical chemistry test through electrochemical detection. We have also shown a concept for multiplexing tests on fabric. Therefore, we believe that a wide variety of tests could be performed on the fabric platform.

ACKNOWLEDGEMENTS

We acknowledge gratefully funding from Grand Challenges Canada (#0002-02-02-01-01) for this project. Weaving support from Manjunath Thahasildar and Viji Ganapathy was crucial for fabricating the sensors.

REFERENCES


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